Learning: Beyond Constructivism

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Learning is in. The number of books being published with the word in their titles is proof... Of course, in this case it's an old pedagogical theme. Still, until very recently, learning has been far from the center of research in science education. Indeed, only philosophers and psychologists had become implicated in this field, and even then their query was more a general reflection on "what is learning" in terms of the development of thought. To revitalize this somewhat bogged down approach, one has undoubtedly to understand "how does one learn?" and "above all, on the "conditions, context, and environment which facilitate or block learning," to the extent that it is acknowledged today that it is not lectures frontal presentations that procure learning.

As teachers of science, it's the result, the ensuing performance, that is of main interest to us. Students', or the audience's, mastery of knowledge and their capacity to mobilize it in everyday or professional lives interest us more than the mechanisms underlying learning. I consciously provoke my fellow psychologists in advancing this point of view: the knowledge of operatory and conceptual mechanisms concerns us only when the learner doesn't learn!

And we should add to this the difficulty of shedding light on any given thought process. Learners never have a clear idea of their thought progression, and most of the time are incapable of verbalizing it. We can only infer it from elements we glean from the learning situation. Such is the extent that learning mechanisms, conditions, and strategies work hand in hand.

The study of the conditions facilitating learning, or even of "efficient" pedagogical strategies, at any rate remains very crude. The various constructivist models say nothing, or nearly nothing, about the contexts or parameters of learning, and provide few applications for situations favoring it. Constructivist models remain highly influenced by the idea of "maturation." Students learn following a chronology relating to the succession of development stages, and this chronology still remains nearly impermeable to processes that can facilitate learning. A mere handful of neo-constructivist researchers advance a few elements such as the activities of association (Gagné, 1976; Ausubel et al., 1968; Bruner, 1986) or cognitive conflicts (Perret-Clermont 1979, 1980).

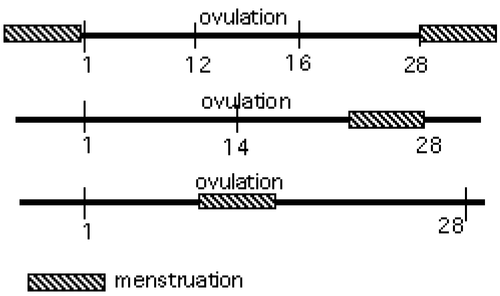
It is true that when we use specific investigations to shed light on the factors facilitating learning, we find it is impossible to define a single type of favorable educative action. The situations or conditions for optimal learning are necessarily multiple. They also depend on the content of what's to be learned, and the knowledge learners are capable of mobilizing.

A great potential for research can be developed along these lines. Our work tries firstly to prove that it is difficult to advance a single model for learning. Learning encompasses an ensemble of multiple and varied activities. Learning mobilizes several disparate levels of mental organization, as well as a considerable number of regulatory loops.

In this text, it thus appears useful to dissect a few procedures brought into play by learners in interaction with the content and contexts of specific learning. How do they gather the information in relation to a question? How do they handle it ? How do they memorize it ? How do they mobilize it ? Etc. At the same time, it becomes important to catalogue the principal parameters nurturing the act of learning. In particular, we will show that all these elements are independent. They overlap with each other in an interactive system.

1. The Limits of Constructivist Models

Learning is not, as most science teachers continue to think, the result of a simple process of transmission and reception. Unlike the effect of light on film, it isn't the result of the impression left in students' minds by the sensorial stimulation from teaching. Spontaneous accord between the students' and the teacher's "mental structures" through the teacher's good performance and students' careful listening is relatively rare, and in any case, never instant, as illustrated in the first diagram.



Some difficulties of comprehension about the menstrual cycle from biology students (males and females) of 25 years old

In light of this pedagogical model's repeated failures and the limits of the behaviorist model, several constructivist models have been developed over the past fifty years (Gagné, 1965, 1976; Bruner, 1991; Ausubel et al., 1968; Piaget and Inhelder, 1966; Piaget, 1967; Vygotsky, 1930, 1934; Varela, 1989). All of them began with the principle that individuals possess their own way of thinking, or even their own "common sense." The organization of learning, the acquisition of knowledge, fundamentally proceeds from activity on the part of the subject. Learning thus becomes a capacity for effective or symbolic, material or verbal action, related to the existence of mental instructions arising from the action. These in turn arise from the active repetition of behavior. Among them, those consisting of representing realities, reconstructing them and combining them in thought, play a fundamental role.

Alas, constructivist models seem rather crude in educational practice. For Ausubel (1968) for example, everything relates to making connections; this is facilitated by the existence of "cognitive bridges" which render information significant in relation to a pre-existing structure. For this author, new knowledge cannot be learned unless three conditions are combined. First, more general concepts must be available, then progressively differentiate themselves during the learning. Second, a "consolidation" must come into play to facilitate the mastery of the knowledge at hand: new information cannot be introduced until preceding information has been mastered. Lastly, the third condition concerns "integrative conciliation," consisting of discerning the resemblances and differences between old knowledge and new knowledge, of discriminating between them and even resolving contradictions; from there, it necessarily leads to remodeling.

Piaget (1976) also supposes that "subjects" process new information according to previously acquired knowledge. They "assimilate" it, and in return, "accommodation" becomes necessary. The result is a transformation of initial knowledge in relation to the new circumstances. For him, it's a question of attaching the new information what is already known, of grafting it onto these notions by taking into consideration the "outlines" at the subjects' disposal.

For when we observe learners in situations in which they are acquiring scientific knowledge, we observe that learning groups together a series of multiple, polyfunctional and pluricontextual activities. Learning mobilizes several mental organizational levels, which at first seem disparate, as well as a considerable number of regulatory loops. To try to explain everything in a single theoretical framework seems nigh impossible -- all the more so as the different constructivist models have been produced in extremely specialized fields.

For example, in the case of learning scientific concepts, everything does not depend on the cognitive structures as Piaget defined them. Subjects who have attained very developed levels of abstraction can reason out new content just as well as young children would! What's involved is not only an operating level, but what we call a global conception of the situation, at once a type of questioning, a frame of reference, of signifiers, of semantic networks (including broader overall knowledge of the context and learning), etc. So many elements orienting the way of thinking and learning, and about which Piagetian theory remains silent.

In the same way, the appropriation of knowledge does not happen exclusively by "reflective" abstraction. In scientific learning, it can at times distort, and indeed, more often than not, creates mutations. A new elements rarely fits in with the contours of previous knowledge. To the contrary, it frequently represents an obstacle to its integration. To try to explain everything in terms of "assimilation" or "accommodation" is highly improbable. Overall, deconstruction should be envisaged hand in hand with all new construction. For learners to be able to grasp a new model or mobilize a concept, their overall mental structure must be transformed. Their framework of questioning is completely reformulated, their network of references largely re-elaborated. These mechanisms are never instant. They pass through phases of conflict or overlapping. Everything is a question of approximation, concernment, confrontation, decontextualization, interconnection, rupture, alternation, emergence, stratification, stepping back and, above all, mobilization.

Let us use an example to illustrate the direction in which we're developing our research. When students learn the nutritional behavior of an ordinary animal, learning consists exclusively of making connections between new knowledge and what they know or think they know (or even making connections between the new and what they already do). Learners already possess a frame of reference concerning nutrition. They know what "eating" means, "what it's for," and "how it happens." In addition, they have procedures for reasoning or acting at their disposal. In this case, information specific to the animal can be provided without any problem (either by direct presentation, or in the form of written or audiovisual documents). They can also register the information directly, as they possess all the elements and cognitive means they need to decode and mobilize it. A single condition can be extremely limiting, which is motivation: the desire to understand the animal's nutritional behavior.

However, if it's a case of an unfamiliar animal, like a sea urchin, mosquito, jellyfish, or paramecium, learning immediately becomes less evident. "Where is the mouth?", "Is swallowing liquid considered eating?", "Where does excrement come out?", "What does digestion mean?": One or many questions can perturb students. To learn, they will have to make their thought systems assimilate - in the Piagetian sense - new, less obvious information. If they need to, they'll embrace this information if it doesn't seem totally pertinent. By this progression, they broaden and restructure their cognitive tools.

Motivation isn't the only limiting factor. First of all, they must decipher information far removed from their habitual ideas. Anything that can't be decoded has no meaning for them, even if it does for the teacher.

To learn, they must make connections between different notions: food, digestion, absorption. For questions presenting cognitive difficulty, they can no longer register all the information directly. They must set in motion a series of procedures to hunt for the information, process each element in it individually, then verify it: the learners become the agents of their own learning. They must still tackle various questions, like "What does eating mean?" and "Why must food be digested?" Favorable learning conditions are those that further the students' investment, that facilitate their questions, their search for, and their processing of information.

Let's take an even more complex example of learning, this time concerning plant nutrition. In this case, students' previous knowledge is incompatible with the message to be learned, so immediate assimilation is impossible. Previously acquired knowledge becomes an obstacle: for learners, the "plant feeds itself in the earth through its roots," and light remains mysterious, at times a "fortifier." It "acts through its heat." As for carbon dioxide, it is a "toxic product" seen as being linked to breathing.

If you tell them that it's the leaves that produce its "living matter," they interpret the leaf as some kind of stomach. At any rate, they can't understand "what produces living matter" or even that a "plant can nourish itself with a gas." A great deal of "deconstruction" must take place in tandem with the construction process. Convincing arguments are not immediately obvious. On top of it, overlaps appear: the students must take their minds off the roots to be able to imagine the role of leaves. This shift in focus, however, cannot be absolute: roots play an indispensable role in the absorption of water, minerals, and even carbon dioxide. As for the parameters affecting the facilitation of this learning, they are multiple and disparate (see Figure 6). On top of it, these parameters function on different levels. A complete didactic strategy must be thought out and implemented to facilitate the learners' operating and conceptual progress.

Learning becomes even more complex when it involves issues concerning genetics, the genetics of populations, regulation, or even environment and health. In these cases, the learning of attitudes or values also comes into play. They are even less easy to transform: to know does not mean an automatic modification in behavior.

2. Allosteric learning

It is easy to see the complexity confronting any teacher of science. To learn, it takes nothing less than the coordination between knowledge -in the strictest sense of the word, strategic knowledge, metacognition and control over the whole. Our proposition is thus very pragmatic. It is not to produce a single additional model of the learner's cognitive processes. At this stage, it seeks rather to go beyond the limits of the constructivist models. To do this, we have attempted to elaborate and validate various micromodels:

- on what learning means in various situations

- on the mechanisms at work

- on the conditions which facilitate learning

This approach is now globally known as the *allosteric learning model*.

Functionally speaking, these micromodels try to reconcile the paradoxical and contradictory aspects inherent in all learning. All mastered knowledge is at once the extension of previously acquired knowledge, which provides the framework for questioning, reference and meaning, and a rupture with it, at least by bending it or transforming it through questioning. Learners learn at once "thanks to," as Gagné writes, "starting with" (Ausubel) and "with" (Piaget), and at the same time, "against" (Bachelard) the functional knowledge in their "heads."

Successful learning is a change in conceptions (see Figure 2), which because it is never neutral for learners, is never a simple process.

CONCEPTION = f(P.R.M.N.S.)

P (or problem) is the set of more or less explicit questions that mobilize the conception, or lead to its implementation. It is the driving force behind all intellectual activity.

R (or set of references) is the set of peripheral knowledge that subjects draw on to formulate their conceptions. in other words, learners rely on other conceptions they've already mastered to generate new conceptions.

M (or mental processes) is the set of all intellectual processes or transformations controlled by the learners. These processes permit them to make connections between elements in their set of references, make inferences, and thus generate and use the conception. Specialists call them operatory invariants.

N (or semantic network) is the interactive organization that has been set in place, arising from the set of references and mental processes. It gives a semantic coherence to the whole. In other words, it is the result of the interplay of all the relationships that have been established between the conception's main and peripheral elements. This process produces a network of meanings, and gives the conception a sense of its own.

S (or signifiers) is the set of notions, signs and symbols necessary for the conception's generation and explanation.

It can even be considered a disagreeable one. The conceptions mobilized by learners lend those learners meaning, and any change is perceived as a threat. It changes the sense of our past experiences. The conception as we have validated it, intervenes at once as an integrator and as a formidable resistor to any new data contradicting the pre-established system of explanations. On top of it, learners must exercise deliberate control over their activity and over the process governing it, and this at various levels which we'll try to list.

All acquisition of knowledge thus proceeds from the complex elaborational activity of learners confronting new information with their mobilized knowledge, then producing new meanings more apt at responding to the questions posed or what they perceive to be the stakes involved. Thus what we call active conceptual sites develop, a sort of interactional structure with a preponderant role in the organization of new information, and in the elaboration of the new conceptual network.

For beyond the description of cognitive strategies, our work is first and foremost didactic. Its aim is to favor the appropriation of knowledge both in and out of school. For even if only learners can learn, they cannot do it alone. Between learners and the object of knowledge, a system of multiple interrelations must be set up. This is never spontaneous. The probability of a learner being able to "discover" all the elements needed to transform his or her questions or further the construction of networks is practically zero. On the other hand, these approaches can be largely favored by everything what we call "environment," the learner's disposition not included.

3. An allosteric environment

Thus we must have in-depth knowledge of the learners' conceptions (see Figures 3 and 4). Far from being limited to notional aspects, it must also include how learners formulate questions, their ways of reasoning, and in what forms meaning emerges for them.

At the same time, it's also a question of putting your finger on the situations, arguments, and documents that can overlap with learners' thoughts to make them progress. A system of multiple interrelations must be set up between learners and the object of knowledge. The probability of learners discovering the whole set of elements capable of transforming their questions or furthering the construction of networks is practically zero (see Figure 5).

At the current stage of research, it is possible to pinpoint these elements in some specific subjects. A micromodel of the networks of parameters and constituent constraints can equally be advanced. Its objective is to decode bit by bit, and in the light of specific knowledge, various types of learning in the form of a "nuanced", systemic and multi-stratified entity, where self-regulating loops and levels of integration are put to the fore.

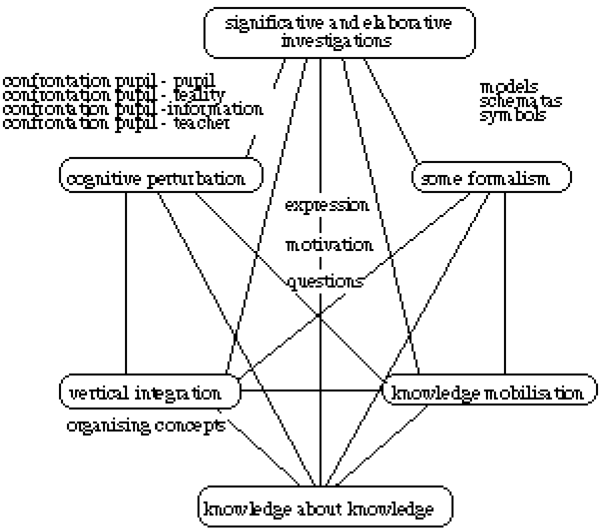


Fig 5. The parameters of an allosteric environment

At the beginning of any learning, a certain degree of dissonance perturbing the cognitive network formed by mobilized conceptions is indispensable. This perturbation creates tension, which disrupts or displaces the fragile balance that the learners' brains have put in place. This dissonance creates progress; without it learners have no reason to change their ideas or way of doing things, and even less reason be concerned with the exposition's theme. They must find an interest in it, a sense in the project or the knowledge at hand.

Later, learners must find themselves confronted with a certain number of significant elements (documentation, experimentation, argumenta-tion) that challenge them and lead them at once to take a step back, and to reformulate their ideas or debate them. In the same way, a certain degree of limited formalism (symbolism, graphs, schemata or models), some kind of thinking aids, must be integrated in their approach. I might add that a new formulation of knowledge doesn't replace the old unless learners find an interest in it and learn to make it function. At these stages as well, new confrontations with adapted situations, with selected information can be profitable in permitting the mobilization of the knowledge.

Lastly, knowledge about knowledge is also desirable. It permits learners to situate the procedures, to step back from them, or to clarify the field to which the knowledge will be applied. For each of them, our micromodels are as many tools for deciphering constraints, and forecasting situations, activities, and teaching practices favoring learning, as shown in Figures 6.

4. Conclusions

Through allosteric learning, the whole question of teaching becomes clearer. New functions for science teachers have thus been corroborated. Their importance lies no longer a priori in their lectures or demonstrations. The efficacy of their action is always situated in a context of interaction with the learners' conceptions and cognitive strategies. First and foremost, is their role in regulating the act of learning, their capacity to engage the students, to provide orientation, or to impart aids in conceptualization.

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The mechanism of photosynthesis is at the biginning of all the food networks of the biosphere. To generate elaborative activity in learners concerning this kind of is not a simple matter. Students have the impression they know that "the plant draws nourishment from the earth," and they are little motivated to know more. Various situations can successfully draw the students in: plants without earth, hydrophonic cultures, plants growing high above ground in tropical forests, lentils, fast-growing plants in glasses. The importance of grasping the subject must be pointed out to learners, either before, or once they've reached a certain stage or level of study. This facilitates questioning and stepping back from the phenomena.Real confrontation is indispensable each time (confrontations between students and reality, students and other students) for them to be able to explain their thoughts in group work. In addition, various exercises should bring them to pick up a set of new data to enrich their experience concerning the question at hand. They must lead them to put their thoughts to the test through observation or experiments (variations of various experimental factors: light, temperature, CO2 concentration, salt content, etc.). They must lead the students to step back from what seems obvious to them, and hopefully reformulate the problem (what does feeding oneself mean?) and/or imagine other relationships (food-energy). A variety of arguments is absolutely essential in this area. The teacher must never be satisfied with a single, quickly-presented argument. In addition, all these elements must be adequate in terms of the students' frame of references; otherwise, they'll elude them.

For students to truly master the scientific process, the approach must be facilitated by student-information confrontations within documentary work (cultivation in various soils, interactions between factors, the role of fertilizer, humus, or manure). All these confrontational activities must convince learners that their conceptions are not adequate, or are incomplete in terms of the problem at hand, and eventually, that others work better.

Next, learners must have access to a certain formalism as an aid to reflection. This formalism can take many different forms (diagrams, models). They should also be easily manipulated to organize new data, or to produce a new structuring of knowledge in terms of reference points. The introduction of a global model can serve as a "nucleus" to bring together information , piece by piece.

This model can be compartmentalized. Certain complementary partial models must be envisaged to clarify each point (the roles of light, chloroplasts, breathing as related to photosynthesis, transduction of energy). Each time, they must be adapted to the students' framework of comprehension. And finally, it should be added that, for the concept of photosynthesis to be truly operational, learners must be provided with situations in which they can mobilize their new knowledge and test its operationality and limits (activities involving cultivation, trophic chains).